Attempt to Control the Invasive Red Alga *Acanthophora spicifera* (Rhodophyta: Ceramiales) in a Hawaiian Fishpond: An Assessment of Removal Techniques and Management Options[1]

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Abstract: *Acanthophora spicifera* (Vahl) Børgesen was unintentionally introduced to Hawai'i in 1950 and has since become the most common nonindigenous algal species in the main Hawaiian Islands. On the west coast of Hawai'i Island it has been documented at three sites, including Kaloko Fishpond in Kaloko-Honokōhau National Historical Park. The fishpond has an open connection to the sea, increasing the risk that *A. spicifera* will establish itself on neighboring shallow coral reefs and rocky intertidal habitats. To diminish that risk and to develop an efficient management strategy, a range of approaches was assessed to control this invasive alga in Kaloko Fishpond. Removal techniques were labor intensive and had limited effect. All experiments showed a substantial initial decrease in algal density, but the long-term effect was minimal because of rapid regrowth. The most promising removal method was the use of submerged shelters to raise local densities of herbivorous fishes. Fishes grazed the alga and quickly reduced the biomass. However, the large number of predators and absence of topographical structure will make it challenging to provide sufficient shelters to increase the herbivorous fish population in the entire fishpond. A management strategy to substantially reduce the algal biomass in the fishpond includes a combination of biological control and periodic manual removal of the alga.

Numerous publications have documented dramatic changes in marine ecosystems after invasive species intentionally or unintentionally were moved across geographical or ecological barriers (Carlton 1987, Boudouresque et al. 1995, Trowbridge 1995, Jousson et al. 2000, Curiel et al. 2001, Smith et al. 2002, 2004, Conklin and Smith 2005). In response to the seriousness of invasive species issues, state, federal, and nongovernmental agencies have developed programs or initiatives to determine the impacts of these species on ecosystem structure and to develop strategies to minimize those impacts. Management of invasives by implementing eradication or control programs, although difficult, can be successful, as seen in numerous terrestrial examples of invasive plant species (e.g., Foxcroft and Richardson 2003, Van Wilgen et al. 2004). Development of management options for control of marine invasives is much more challenging (e.g., Conklin and Smith 2005). Possibly the only presumed successful marine example is the short-term "injection" of bleach under a tarped-off area for *Caulerpa taxifolia* in a coastal lagoon of southern California (Woodfield and Merkel 2005).

Hawai'i is a major recipient of introduced species. A conservative estimate of the number of marine introduced species in Hawai'i is in the hundreds (Carlton 1987). There are 19 documented species of introduced macroalgae in Hawai'i, at least five of which have

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become invasive: *Acanthophora spicifera*, *Avrainvillea amaldelpha*, *Gracilaria salicornia*, *Hypnea musciformis*, and *Kappaphycus* spp. (Rodgers and Cox 1999, Eldredge and Carlton 2002, Smith et al. 2002, 2004). To date, *A. spicifera* and *Kappaphycus* spp. are the only taxa that are known to be sexually reproductive on a regular basis in the Hawaiian Islands (J. E. Smith, pers. comm.), thus increasing their dispersal potential. In Kāne'ohe Bay, O'ahu, *Kappaphycus* spp. were introduced on the assumption that they would not spread (Russell 1983). However, surveys conducted in 1996 (Rodgers and Cox 1999), 1999 (Woo 2000), and 2002 (Conklin and Smith 2005) found that the algae had spread as far as 6 km away from the introduction site and were continuing to spread northward in the bay, where they were overgrowing live coral. Once invasive macroalgae have become established, eradication is difficult and costly, and can lead to high economic losses (Cesar and Beukering 2004).

Acanthophora spicifera (Vahl) Børgesen, 1910, a marine red alga, arrived in Pearl Harbor, O'ahu, from Guam on a barge in the 1950s (Russell 1992). Now it is the most common nonindigenous algal species in the state and displaces many native species where it is abundant (Smith et al. 2002). The success of *A. spicifera* in invading benthic habitats is attributed to: (1) its ability to reproduce both sexually and vegetatively (by fragmentation); (2) successful epiphytism; and (3) its adaptability to a wide range of hydrological conditions (Russell 1992). When and how *A. spicifera* first entered Kaloko Fishpond is unknown. Despite its dominance on other islands, on the west coast of Hawai'i Island its presence has been documented at only three sites: Pu'ukoholā Heiau National Historic Site (Ball 1977; L. Basch, unpubl. data, 2005), Pu'uhonua o Hōnaunau National Historical Park (C. Squair, unpubl. data, 2006), and Kaloko-Honokōhau National Historical Park (Marine Research Consultants 2000, Smith et al. 2002). Only in Kaloko Fishpond, located in Kaloko-Honokōhau National Historical Park, has the alga been observed in abundance. The alga might have been present at low levels within the pond for much longer (beginning sometime after the species' wider introduction to the west coast of Hawai'i), but it apparently did not become invasive in Kaloko Fishpond until the late 1990s. The presence of this species was not mentioned in a 1971 evaluation of fishponds (Kikuchi and Belshé 1971), nor in a 1988 marine inventory study (Chai 1991) nor in a 1996 biological and water quality study (Brock and Kam 1997). The first report of *A. spicifera* being abundant throughout the fishpond was made in 2000 (Marine Research Consultants 2000). Currently, it is the dominant macroalgal species in the pond.

In the last three decades, two important alterations have changed the hydrology of the fishpond and might have influenced the susceptibility of the pond to invasion by *A. spicifera*. First, the condition of the fishpond wall separating the pond from the ocean has been continuously changing: It was left to deteriorate from wave and wind action from the 1970s to the late 1990s, at which time rehabilitation efforts began (Bond and Gmirkin 2003). Alterations in the integrity of the wall led to changes in water quality within the pond and the rate of exchange with adjacent ocean waters, and are therefore probably associated with shifts in the pond biota. Second, mangroves that had invaded the pond periphery in the 1980s were removed in the early 1990s (Bond and Gmirkin 2003). Accumulation of detritus in mangrove stands would have changed the bottom sediment and water quality, and likely also affected the pond biota. In addition, upslope development beginning in earnest two decades ago has most likely led to nutrient increases in the groundwater that enters the fishpond.

In the summer of 2003, the first comprehensive study to quantify the distribution and density of *A. spicifera* in Kaloko Fishpond was conducted. A 20–m grid was laid out over the pond and at each grid point the presence and, if present, the abundance (from sparse to concentrated) of *A. spicifera* was scored. At that time, the pond bottom was 48% covered by *A. spicifera* either as drift, embedded in silt or sand, or attached to oysters or rock substratum (National Park Service, unpubl. data). A primary concern for Park resource

managers was, and is, that *A. spicifera* might spread to the intertidal zone and coral reefs just seaward of Kaloko Fishpond. Fragments of drift *A. spicifera* have escaped the pond through the sluice channels (M.W., pers. obs.). The current absence of visible *A. spicifera* on the adjacent reef could be because the alga is not able to establish outside the pond, perhaps due to locally high-grazing intensity, or because propagule pressure has so far been insufficient to promote establishment. However, because of the prevailing surface and deep-water currents offshore of Kaloko Fishpond (Storlazzi and Presto 2005), we cannot discount the potential for this alien alga to establish on nearby shallow reefs.

To reduce the risk of *A. spicifera* spreading to adjacent reefs, the following techniques were used from April to December 2006, to determine the feasibility of controlling or eradicating *A. spicifera* in Kaloko Fishpond: manual removal, shading of the benthos, and use of herbivorous fish (biocontrol). Chemical-control methods were not explored in this study because of the associated risks to aquatic organisms and ecosystems within this national park unit. It soon became apparent that *A. spicifera* regrew rapidly after manual removal. Therefore, trials to determine an efficient manual removal technique were also conducted. These included cropping to three different specific thallus lengths (minimum viable thallus length trial), repeatedly removing the same alga (repetitive removal trial), and removing attached algae with their hard substrate and replacing the substrate after a period of drying (substrate removal/replacement trial). In each case we measured extent and speed of recovery of *A. spicifera* populations for periods of up to 4 months.

MATERIALS AND METHODS

Study Site

Kaloko Fishpond is a 4.5–ha ancient Hawaiian fishpond (Figure 1) located in Kaloko-Honokōhau National Historical Park on the west coast of Hawai‘i Island. It is a shallow (maximum depth 3.5 m, mean depth 1.5 m) natural embayment with a human-made dry-stack stone wall partially closing it off from the ocean. Two sluice channels in the wall allow some water circulation between the ocean and pond. The fishpond seawall deteriorated substantially from about 1970 until rehabilitation began in 1998 because of the impact of winter storm swells (Bond and Gmirkin 2003). At the time of the study about 60% of the wall and one sluice channel were rehabilitated. Work on the wall continued throughout the study. Kaloko Fishpond water is stratified due to freshwater springs and seepage from cracks in the basalt bottom. The dominant substrate is silt composed of decomposing organic material varying in depth from a few centimeters on the ocean side of the pond to at least 1 m on the inland side, often with anoxic conditions (Kikuchi and Belshé 1971). Allochthonous sand is predominantly found on the ocean side of the pond. The remaining bottom type is hard substrate such as basalt rock and oyster conglomerates with an associated biota that includes anemones, fireworms, sponges, tunicates, and brittle stars. The benthos is mostly blanketed by an algal mat composed of a rich microflora assemblage (cyanobacteria, diatoms, dinoflagellates) and macroalgae. Preliminary surveys in April 2005 showed that the fishpond bottom was 66% covered by *A. spicifera*, and that sand and oysters were the main algal substrate types. The alga was mostly absent on silt bottoms. Oysters are primarily found in shallow water ($\leq$1 m) and were therefore easy to reach for removal efforts. Oyster islands are present in 14% of the fishpond and are concentrated in the NW corner of Kaloko Fishpond. That area is where we concentrated our removal efforts.

Measurement of Algal Coverage and Periodic Surveys

It was difficult to get a good estimate of algal cover due to the three-dimensional structure of the plants, very low visibility (sometimes as low as 25 cm), and the daily movement of unattached drift algae. A 25 by 25 cm quadrat with nine, 1–cm^2 sampling squares evenly distributed was used to calculate “algal coverage.” Presence or absence of *A. spicifera* was

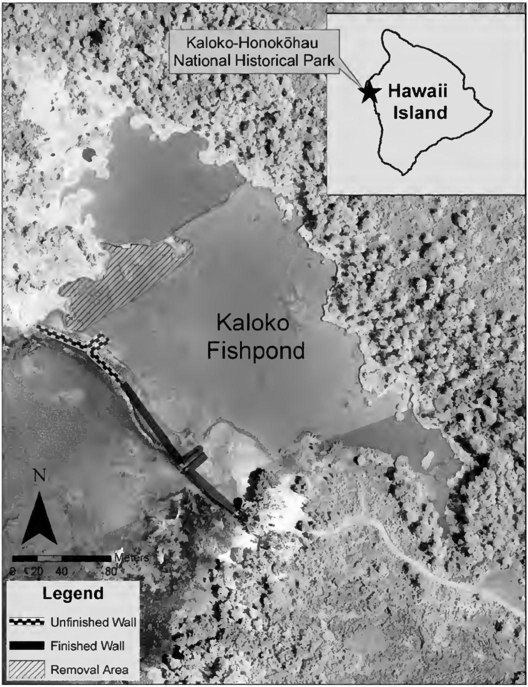

FIGURE 1. Kaloko Fishpond and adjacent reef shelf with modifications of the seawall drawn in for an up-to-date image. The removal area (lined) in the northwest corner is the 2,200 m^2 removal and experimental area of this study. The lighter areas within the removal area are the oyster islands. Kaloko Fishpond is located in Kaloko-Honokōhau National Historical Park just north of Kailua-Kona, on the west coast of Hawai'i Island.